MSL Project Team 2018-19

NASA Jet Propulsion Laboratory
California Institute of Technology

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Commanding Curiosity from the Couch :
## MSL Remote Operations, Challenges, and Path Ahead

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Jet Propulsion Laboratory
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Mission Operations Overview

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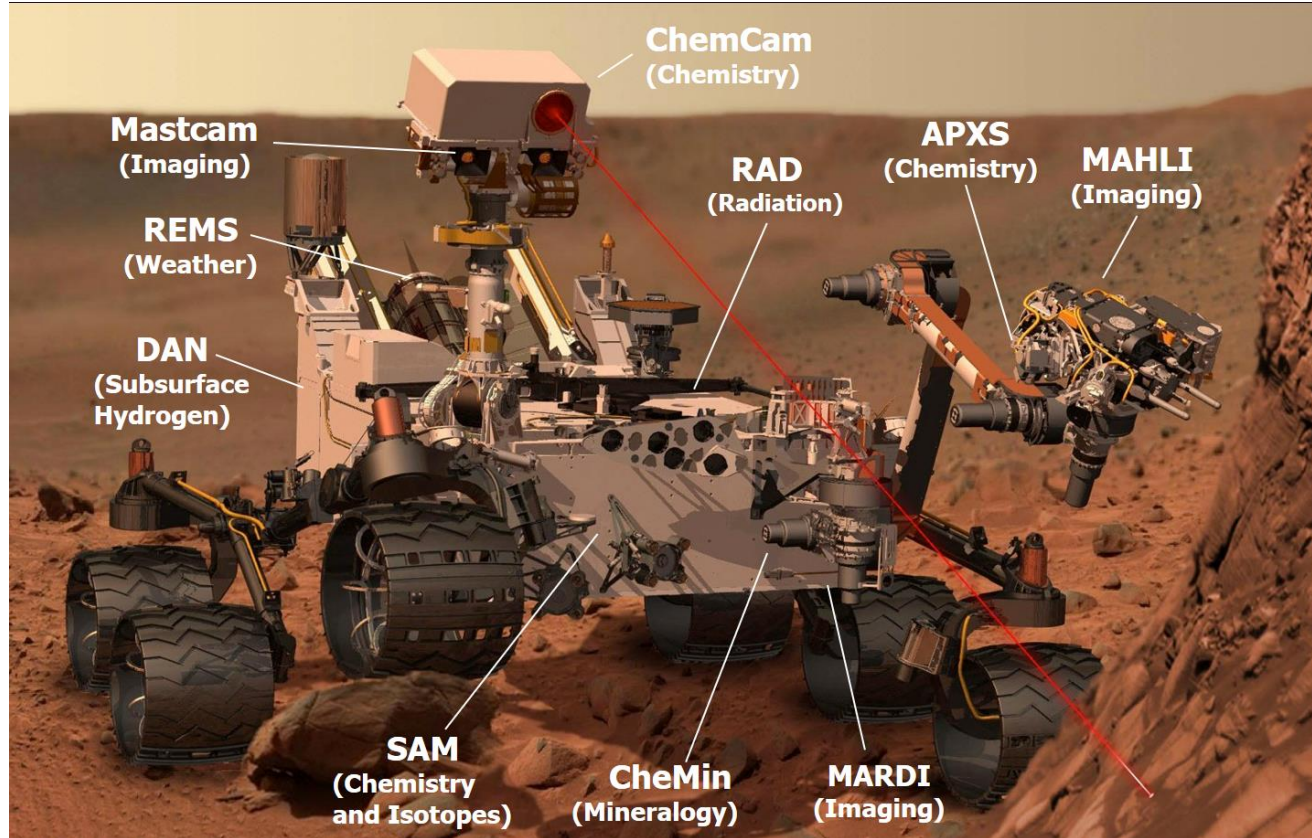
Surface Operations Components

sol	Martian Day, ≈ 24.6 Earth Hours
DSN	Deep Space Network, an Earth satellite dish network for communication with spacecraft
GDS	Ground Data System, ground computer network at JPL used in operations
Downlink	**Tactical** process by which telemetry is processed and spacecraft health is assessed
Uplink	**Tactical** process by which activities are scheduled, sequences are generated for cmd bundle
Supratactical	Process by which future (1-14day) of activities are planned
MSLICE	Activity planning and commanding software, used by Science Planners
RSVP	Rover Sequencing and Visualization Program, used by Rover Planners
VSTB	Vehicle System Testbed, physical testbed model of MSL
ECAM	Engineering Cameras, used for navigation, target selection, and documentation
MAHLI	Mars Hand Lens Imager, instrument on the robotic arm
DRT	Dust Removal Tool, instrument on the robotic arm
SAM	Sample Analysis at Mars, instrument on chassis used for analyzing samples
RTG	Radioisotope Thermoelectric Generator, spacecraft power source

Surface Operations Roles

|	
TDL	Tactical Downlink Lead, heads up the Downlink process
PDLs	Payload downlink leads, processes instrument downlink telemetry
Subsystem Chairs	Processes subsystem downlink telemetry, and responsible for subsystem health
TUL	Tactical Uplink Lead, manages Uplink process
Mission Lead	Oversees Downlink and Uplink processes
SP	Science Planner, schedules all spacecraft activities and models resource usage
RP	Rover Planner, sequences spacecraft mobility and robotic arm motion.
PULs	Payload Uplink Leads, sequences spacecraft instruments
SOC	Science Operations Coordinator, coordinates tactical and supra-tactical sci. planning
SOWG	Science Operations Working Group, group of scientists participating in tactical planning
SuTL	Supratactical Uplink Lead, manages Supratactical process

Telemetry

Downlink
Uplink
Supratactical

Telemetry

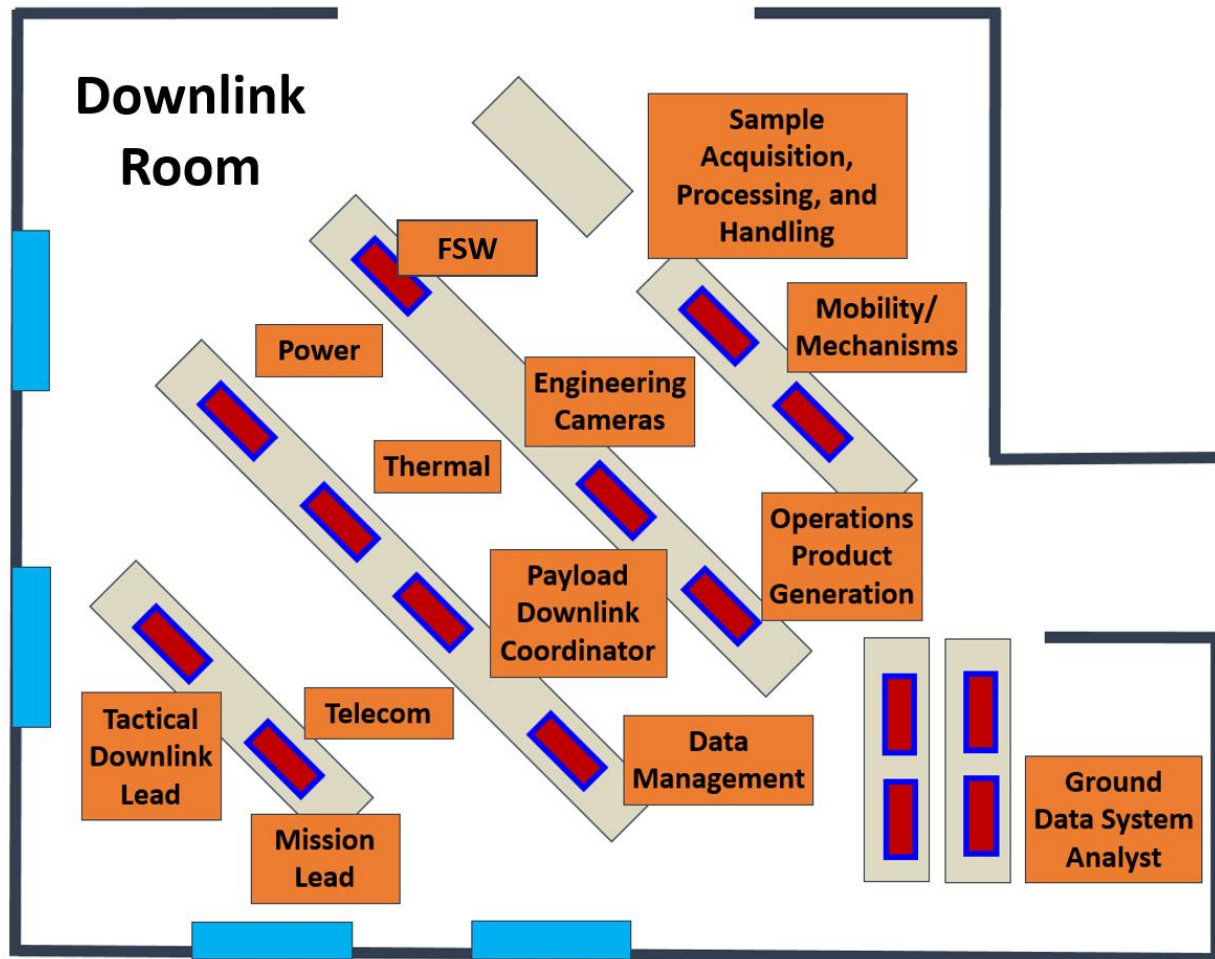Telemetry

Command Bundle
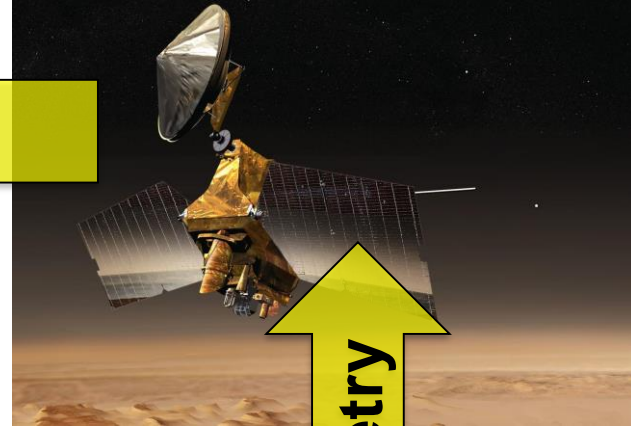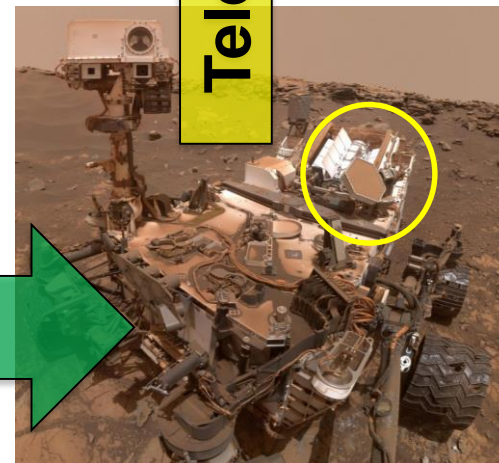
Mission Operations Overview

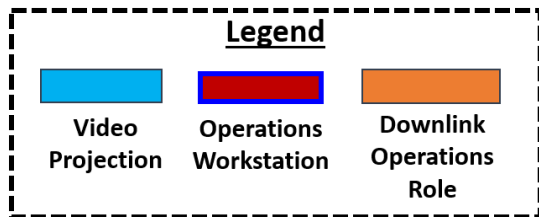**Time Critical**

Asynchronous Communication Channels

Serial and Parallel Processes

Rich and Interactive Computing Environments

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Commanding Curiosity from the Couch : MSL Remote Operations, Challenges, and Path Ahead

In Person Mission Operations: Downlink Room

Legend

Video Projection	Operations Workstation	Downlink Operations Role

Downlink Room

- Sample Acquisition, Processing, and Handling
- FSW
- Mobility/ Mechanisms
- Power
- Engineering Cameras
- Thermal
- Operations Product Generation
- Payload Downlink Coordinator
- Tactical Downlink Lead
- Telecom
- Data Management
- Ground Data System Analyst
- Mission Lead

In Person Mission Operations: Uplink Room

Sequence Integration Engineer

Eng. Uplink Lead

ECAM Payload Uplink Lead

Strategic Rover Planners

Mission Assurance

Science Ops. Coordinator

Tactical Uplink Lead

Mission Lead

Science Planner

Tactical Rover Planners

Supra-Tactical Uplink Lead

Legend

| Video Projection | Operations Workstation | Supratactical Whiteboard | Uplink Operations Role |
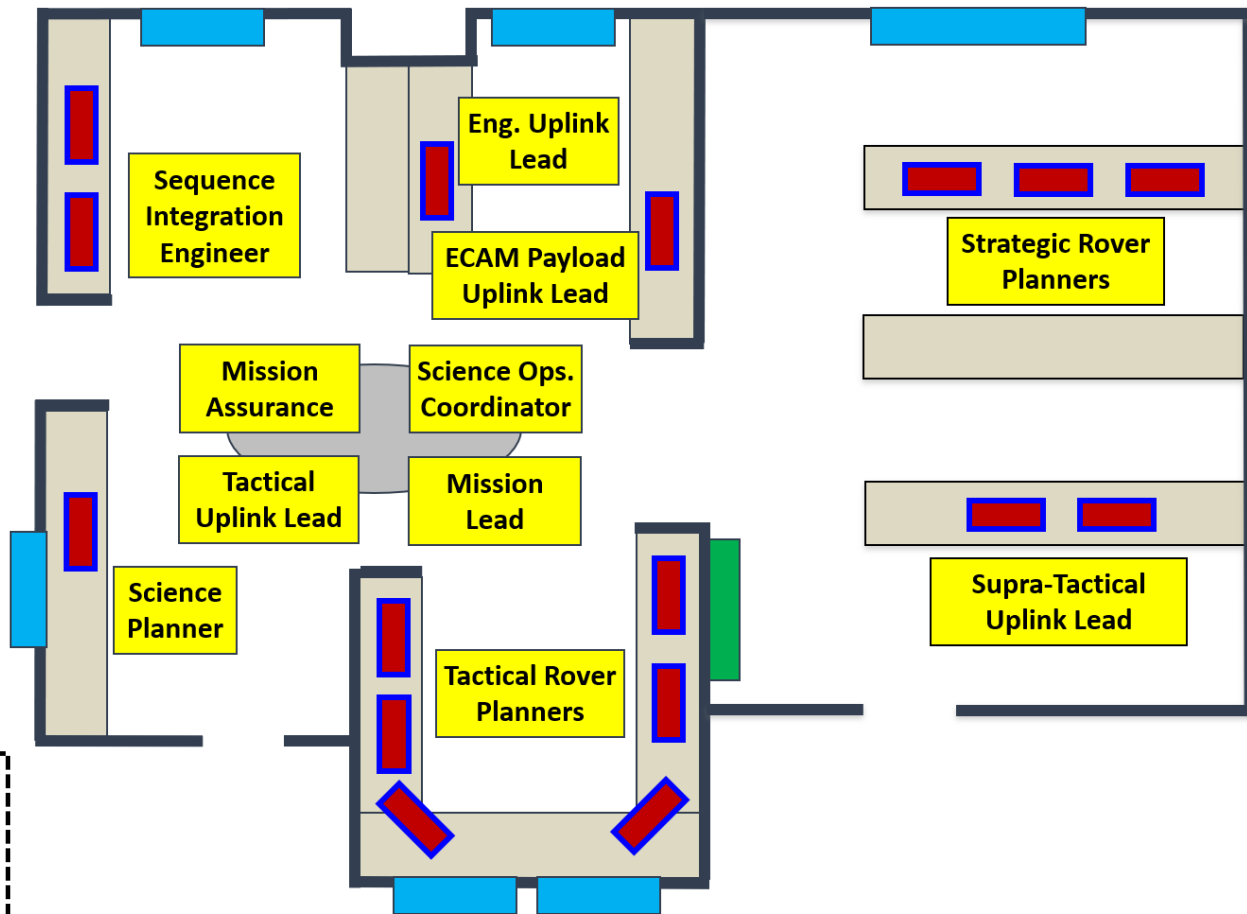
In Person Mission Operations
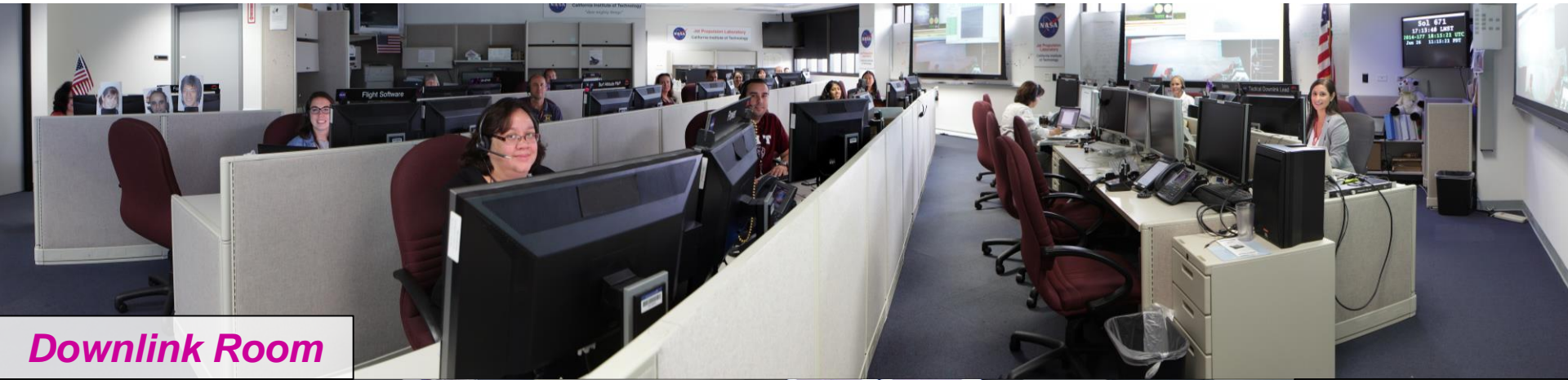
Downlink Room

Uplink Room

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Existing Remote Operations Capabilities

Remote Collaborators

Web Conferencing

VNC Remote Desktop

Chat Rooms

3/11/2022

Challenges to Fully Remote Operations

Software Access and Tool Performance

Communication Channels

Individual Environment, Hardware, and Local Factors

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Detailed Changes

Structure of Remote Connections
- Personnel distribution and network topology to facilitate remote operations shifts

Remote Use of Software Tools
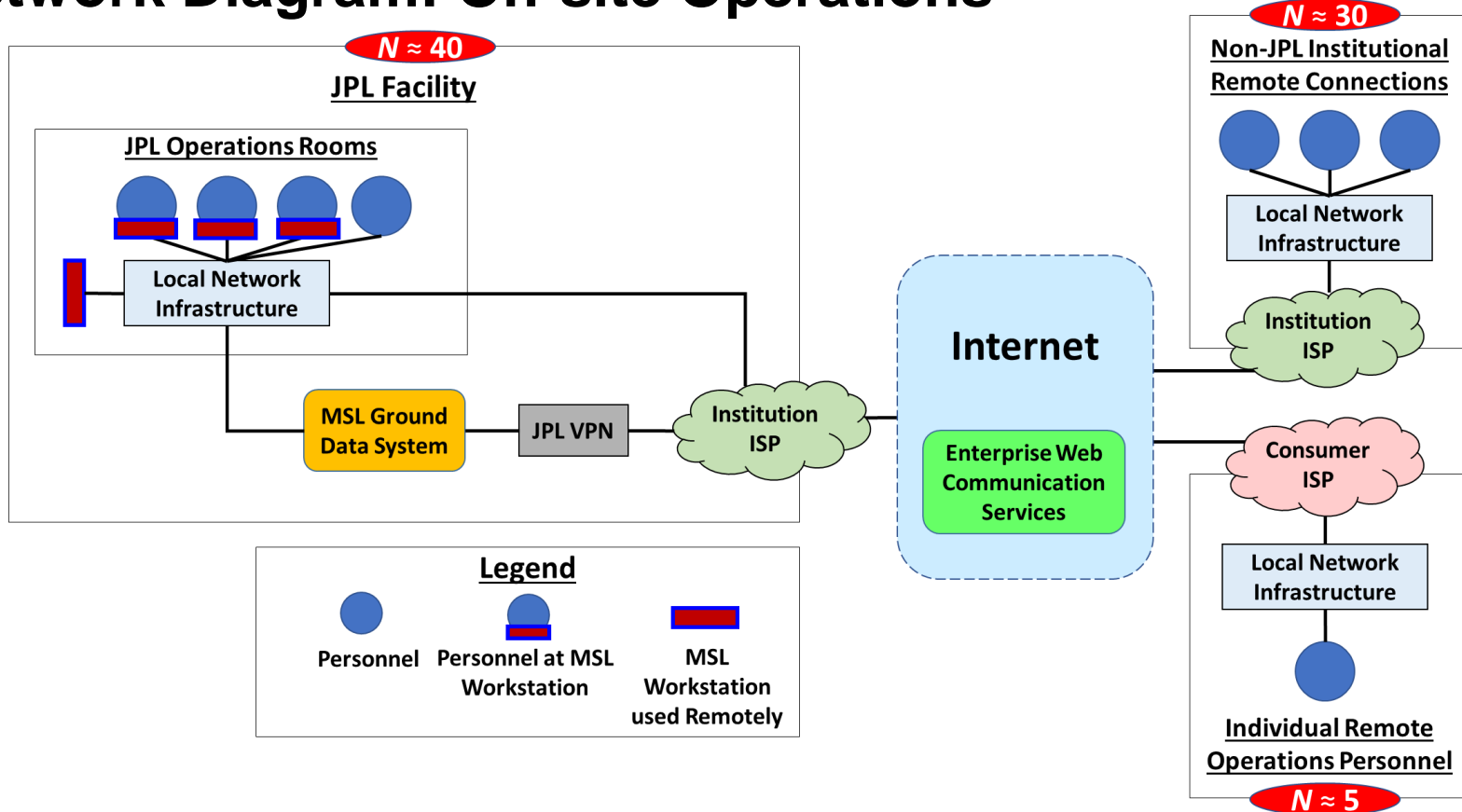- Expanded use of remote desktop tools for workstation access

Expansion of Communication Channels
- Increase of communication channels to replace in-person discussion
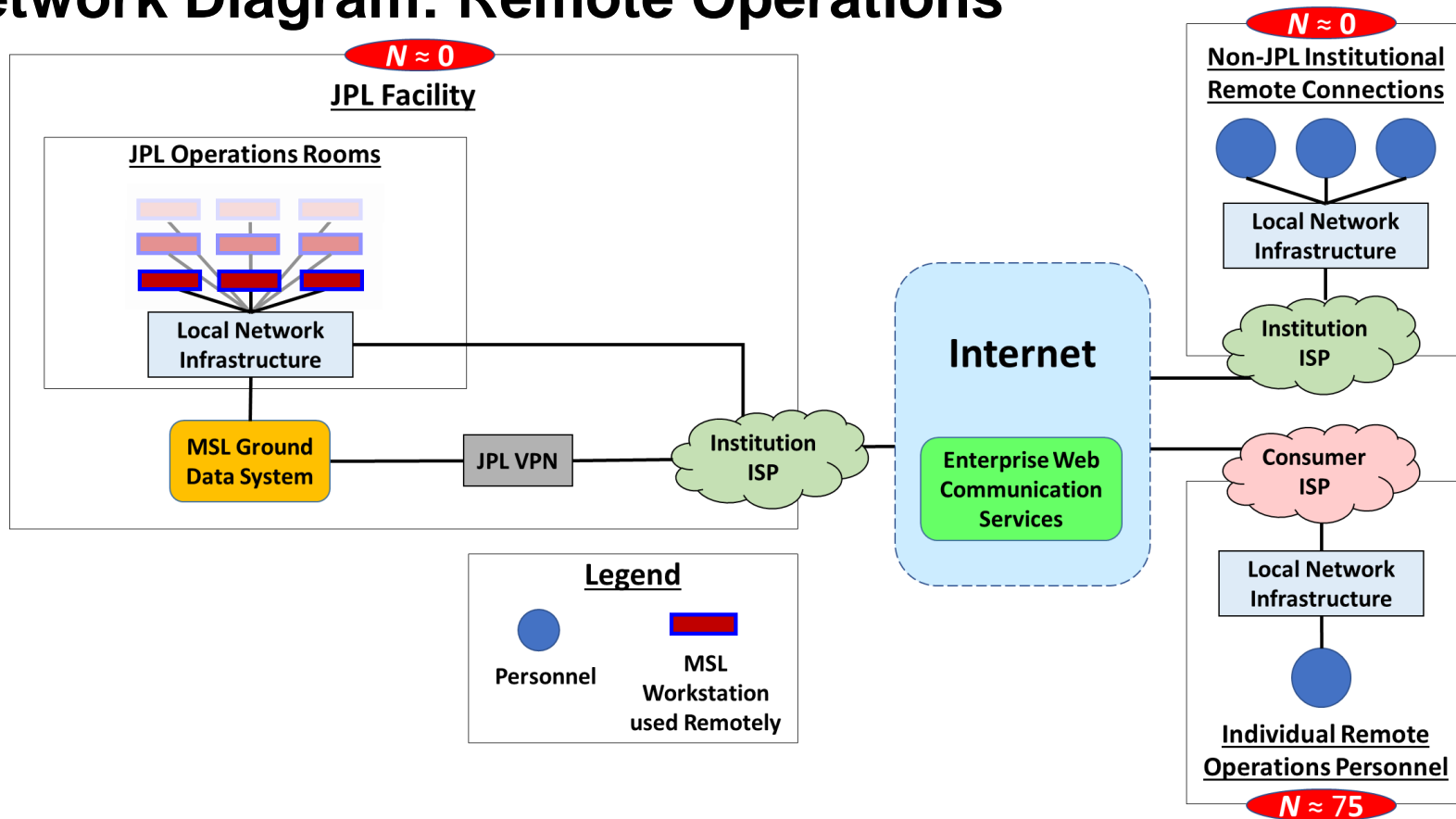
RP Staffing and Plan Content Adjustments
- Adjusted staffing and allowable plan complexity to compensate for communication challenges

Network Diagram: On-site Operations

Network Diagram: Remote Operations

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Communication Channels: On-Site

	Operations Groups					
	Tactical Uplink	**Tactical Engineering Uplink**	**Tactical Rover Planner**	**Tactical Science Uplink**	**Science Operations Coordinator**	**Supra-Tactical**
Enterprise Web Conference Rooms	0	1	1	1	2	1
MSL Hosted Chat Rooms	1	5	3	7	13	3
Enterprise Chat	0	0	0	0	0	0

Communication Channels: Remote

INCREASED UNDER REMOTE	Operations Groups					
	Tactical Uplink	Tactical Engineering Uplink	Tactical Rover Planner	Tactical Science Uplink	Science Operations Coordinator	Supra-Tactical
Enterprise Web Conference Rooms	1	1	2	1	4	1
MSL Hosted Chat Rooms	1	6	3	7	15	4
Enterprise Chat	1	1	1	1	1	1

Communication Channels: Virtual Whiteboard

Supratactical Sol Path							
Updated by SUTLs and SOCs					Nominal Remote-Ops	Restricted Remote-Ops	

(insert new weeks below this row with [right click->insert cells->shift down], see templates on right starting in column O -->)

Monday 9:30 start	Tuesday	Wednesday 10 AM start	Thursday	Friday	Saturday	Sunday	Monday (MLK holiday)
1/11/2021	1/12/2021	1/13/2021	1/14/2021	1/15/2021	1/16/2021	1/17/2021	1/18/2021
Sol 2999	Sol 3000	Sol 3001	Sol 3002	Sol 3003	Sol 3004	Sol 3005	Sol 3006
SB	SB					RS2C	REMS only
Arm bb: MAHLI Wheel imaging for RPs and 2x 25 cm mahli + stow	Drive + SAPP Sun Update + PDI for T&G	USB	Untargeted SB	SB	SB (1 hr)	SB (1 hr)	
	AM Passive Sky with TGO		Thermal Char. of Non-Prime PAM		CS (1 target with DRT)	FMWI + Drive (84m), PDI + for CS	
		Chemin Empty Cell Analysis			Evening/Overnight APXS		
						AM ENV	
				No mahli open cover			

Monday	Tuesday	Wednesday	Thursday	Friday 10 AM start	Saturday	Sunday	
1/4/2021	1/5/2021	1/6/2021	1/7/2021	1/8/2021	1/9/2021	1/10/2021	
Sol 2992	Sol 2993	Sol 2994	Sol 2995	Sol 2996	Sol 2997	Sol 2998	
Arm1: Unstow, 2x 5 cm mahli, arm move for imaging	Arm1: RS2C + 5 cm mahli (Ratharsair)	RS2C+5 cm mahli (post retract of APXS footprint)	RS2C + 1 post retract 5 cm				
SB	SB (1 hrs)	SB	SB (1 hr)	SB (1 hr)	RS2C	SB (30 min)	
Arm 2: 2x(25, 5, 5 mahli) + proxmode placement	Arm2: mahli REMS UV + 2x(2 cm mahli on Ratharsair and Airor) + proxmode placement	1 CS target (ripple crest) + proxmode placement	Drive + PDI (for CS)	CS (1 target with DRT)	SB (1 hr)	Drive (60m) + PDI	
Overnight APXS on trough	Overnight APXS on Airor	Overnight APXS on ripple crest		Evening/Overnight APXS	SAM CH4 enrichment ActID351	AM ENV	
REMS on Holiday	**REMS on Holiday**	**REMS on Holiday**		**REMS on Holiday**			

Preparations & Testing For Remote Operations

Individual Testing

- **Members of each team tested network connections, VPN, individual tool performance**
    - **Most met 20-25Mbps DL speed for home ISP**
- **Results informed prerequisites and tall tent poles for end-to-end test**

Equipment Distribution

- **Headphones**
- **3D glasses**
- **Dual Monitors**
- **Distribution conducted at JPL on the last days of on-site work**

End-to-End Testing

- **March 12, 2021**
- **Tested conducted on main ops venue for a future plan, sol 2848**
- **Downlink was processed remotely from the most recent plan**
- **Fictitious uplink plan was put together remotely involving engineering and science uplink team**
- **Duration only increased 1.2hr longer than a normal shift.**

Calendar – March 2020

SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
	Planning starts with target date of 3/12 for testing		Assess remote impacts and staffing resilience Start assessing remote software tool options	Start thread test concepts leveraging on previous GDS update	Team members begin testing from home and developing procedures	
8	9	10	11	12	13	14
	Thread Tests set for 3/12	Thread Test Planning sessions VNC service mode evaluation	Deploy VNC service mode to test machines Create new chat rooms and test web conference lines	**JPL Telework Exercise** **Successful DROTT and ROUTT** Order additional equipment	Inventory spare monitors, keyboards, mice, cables	
15	16	17	18	19	20	21
	Assess readiness for remote ops: Downlink: Go Uplink: by 3/18 Distribute newly arrived and spare MSL equipment to departing team	**JPL starts mandatory telework** **Downlink supports remotely** **Uplink stands down to incorporate lessons from ROUTT**	Update procedures and train team members Setup permanent new chat rooms Team continues testing from home	Create and debug new ops web conference rooms Update ops machines with enhanced VNC Remove ROUTT data from ops venue	**Successful First MSL remote ops shift – Edinburgh Full Drill**	
SUN	MON	TUE	WED	THU	FRI	SAT

PLANNING DAY	NON PLANNING DAY

DROTT: Downlink Remote Ops Thread Test

ROUTT: Remote Operations Uplink Thread Test

Feasibility for long term operations

Human Factors and Sustainability
- Initially stress levels increased and we had some overloading of ops roles. After 6 months things have stabilized.

Mission Performance and Productivity
- Completed 4 remote drill campaigns, including 2 wet chemistry experiments with SAM which required special preparation.
- Traversed over 2km fully remote.
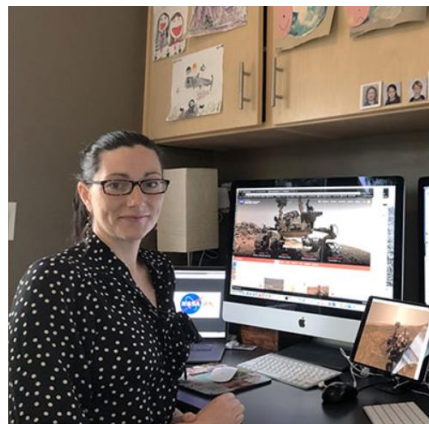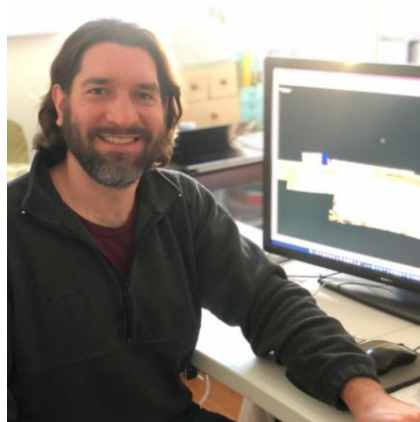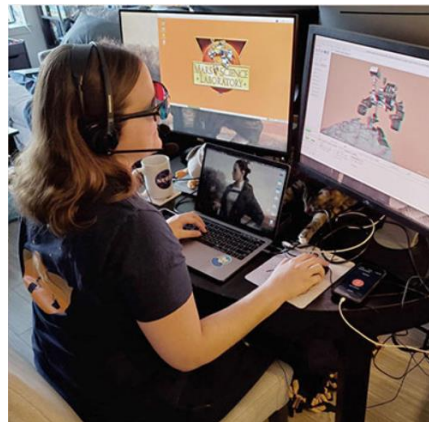- Development and test of FSW update ongoing.

Training
- Training is especially difficult remotely due to reduced feedback mechanisms. Several roles have successfully been trained.
- Team has instituted tactical simulation to provide more training opportunities

Other Mission and Returning to In-Person Ops
- Other Mission include M2020 have adopted some of the MSL approaches to enable partial or fully remote operations.
- Several aspects of remote will be carried forward to in-person ops upon our return to JPL.

Authors at their home workstations

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Acknowledgements

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